CHAPTER 2. AIR IN CULVERT SYSTEMS

2-1. Experience with Air in Culvert System.

a. At several old locks (notably Ohio River Lock No. 41, old Wilson Locks on the Tennessee River, and Mississippi River Lock No. 1) portions of the roofs of the culverts between the filling and emptying valves were at elevations higher than the lower pool. This resulted in air seeping into the culvert system and forming pockets along the roof when the chamber water surface was at lower pool level. In the filling operation, the air pockets were compressed and forced along the culvert until expelled through an available exit (valve well, bulkhead recess, or ports into the lock chamber). The air emerged with such explosive force that it endangered personnel on the lock walls, created disturbances in the chamber which were hazardous to small craft, and increased hawser forces on moored tows. Conditions at these locks were mitigated somewhat by installation of blowoff vents, but it was concluded that all air should be sealed from the filling system.

b. When the 92-ft-lift McNary Lock[a] was constructed on the Columbia River six 12-in.-diam air vents, two in the culvert roof and two in the upper portion of each sidewall, were installed immediately downsteam of each valve. During initial operation of the lock, the air vents at the filling valves were capped. Pounding noises, resembling thunder or cannon shots, seemed to come from the bulkhead slots on the downstream sides of the filling valves when the valves were partially open. It was found that opening one of the 12-in.-diam air vents in the roof of the culvert at each valve virtually eliminated these noises. Consequently, the lock has been operated with one air vent open at each valve. Air is drawn through the vent into the culvert system during the valve opening period, is entrained as small bubbles in the highly turbulent flow, and emerges in the lock chamber so entrained that it merely causes the water to look milky. When the valve reaches the full open position, air ceases to be drawn through the vent and all air is rapidly purged from the culvert system still entrained in the flow as small bubbles. No operation difficulties or hazardous conditions have resulted from admitting this controlled amount of air to the culvert system during the valve opening period. Other locks, notably the 63.6-ft-lift Holt Lock on the Warrior River and the 48-ft-lift Millers Ferry Lock on the Alabama River, operate satisfactorily with a controlled amount of air admitted to the culvert system during the valve opening period. In fact, model tests on Holt Lock indicated that a controlled amount of air would reduce hawser forces on moored tows. This seems reasonable since bubble screens are used to dissipate waves and surges in harbors.

c. Thus, while pockets of air in the culvert system are very undesirable, admission of a controlled amount of air during the valve opening period has proved beneficial at high-lift locks.

2-2. Recent Field Tests of Cavitation Conditions.

a. Tests were made at three locks--Holt on the Warrior River in Alabama, John Day on the Columbia River in Washington-Oregon, and Millers Ferry on the Alabama River in Alabama--to determine conditions under which a controlled amount of air is needed to quiet the pounding noises such as those heard during initial operation of McNary Lock. A summary of certain of the results of these tests is given in Appendix A.

b. In order to evaluate cavitation potential at various projects, a cavitation parameter, K, is used. The form of this parameter used for lock culvert valves is:

$$K = \frac{P+(P_a - P_v)}{V^2/2g}$$

where

P = gage pressure at the top of the vena contracta of the jet emerging from the partially open valve, ft

P_a = atmospheric pressure, ft

P_v = vapor pressure of water, ft

V = velocity in vena contracta of the jet emerging from the partially open valve, fps

g = acceleration due to gravity, ft/sec^2

A value of 33.0 ft has been used for the term $P_a - P_v$ in all cases. This probably is correct within 0.5 ft for conditions at existing locks, and available data do not warrant a more refined value. P and V are computed by a program developed at the U. S. Army Engineer Waterways Experiment Station (WES program, Appendix B) and are independent of local pressures on the roof of the culvert, which are influenced by changes in culvert geometry. The value of this parameter at which cavitation is incipient is termed the cavitation index, K_i. Under this procedure, the value of K_i varies with changes in the culvert geometry.

c. Values of the cavitation parameter, K , for the tests described in table A-2 are plotted against percent expansion of the culvert roof in figure 2-1. Also, a line defining K_i recommended for design purposes is shown in this figure. Since Holt test 2 (only one boom) obviously was near conditions for incipient cavitation while John Day test 3B (several booms) was well within cavitation conditions, there is logic in the manner in which the K_i line is drawn. At Holt and John Day Locks where the culvert roofs slope up downstream from the filling valves there is additional backflow of water into the low pressure zone downstream from the valve. This additional circulation, or water venting as it is sometimes called, results in an increase in pressure on the culvert roof. Measured pressure increases have been plotted as pressure drop (initial lock water surface to minimum gradient) reductions in figure 2-2. If this pressure increase was the only quantity changed then computations with measured pressures should allow establishment of a single K_i value for all roof geometries. This is not supported by available data. It is considered probable that both the velocity and depth at the vena contracta also are modified, but accurate measurements to establish the degree of modification would be difficult.

2-3. Selection of Elevation for Culvert Valves.

a. In design, the lock valves must be placed either at an elevation that will result in the minimum value of K being not less than K_i or at an elevation that will result in negative pressures on the culvert roof and vents must be provided in the negative pressure zone. If an elevation for the culvert is determined such that the minimum value of K equals K_i , then the culvert should be lowered an additional distance equal to one-tenth of the lift as a safety factor. If vents are to be provided, the culvert should be placed at an elevation that will result in about 10 ft of negative pressure on the culvert roof during normal operation. In locks with lifts up to 100 ft, this will result in the pressure gradient dropping below the culvert roof when or before the valve is about 35% open and thus will provide aeration throughout the critical period of the operation cycle. WES program, Appendix B, computes an elevation for the pressure gradient and this gradient elevation can be used directly to determine the pressure on a level roof but must be modified for upsloping roofs as indicated in figure 2-2.

b. A third alternative to the two procedures suggested in the preceding paragraph is to ignore cavitation potential in siting the valves and to use a slow or delayed valve opening schedule such as is recommended for John Day Lock, see paragraph A-11. In an existing lock this may be necessary but it imposes an undue limitation on a new design. A fourth method that has been proposed but is questionable

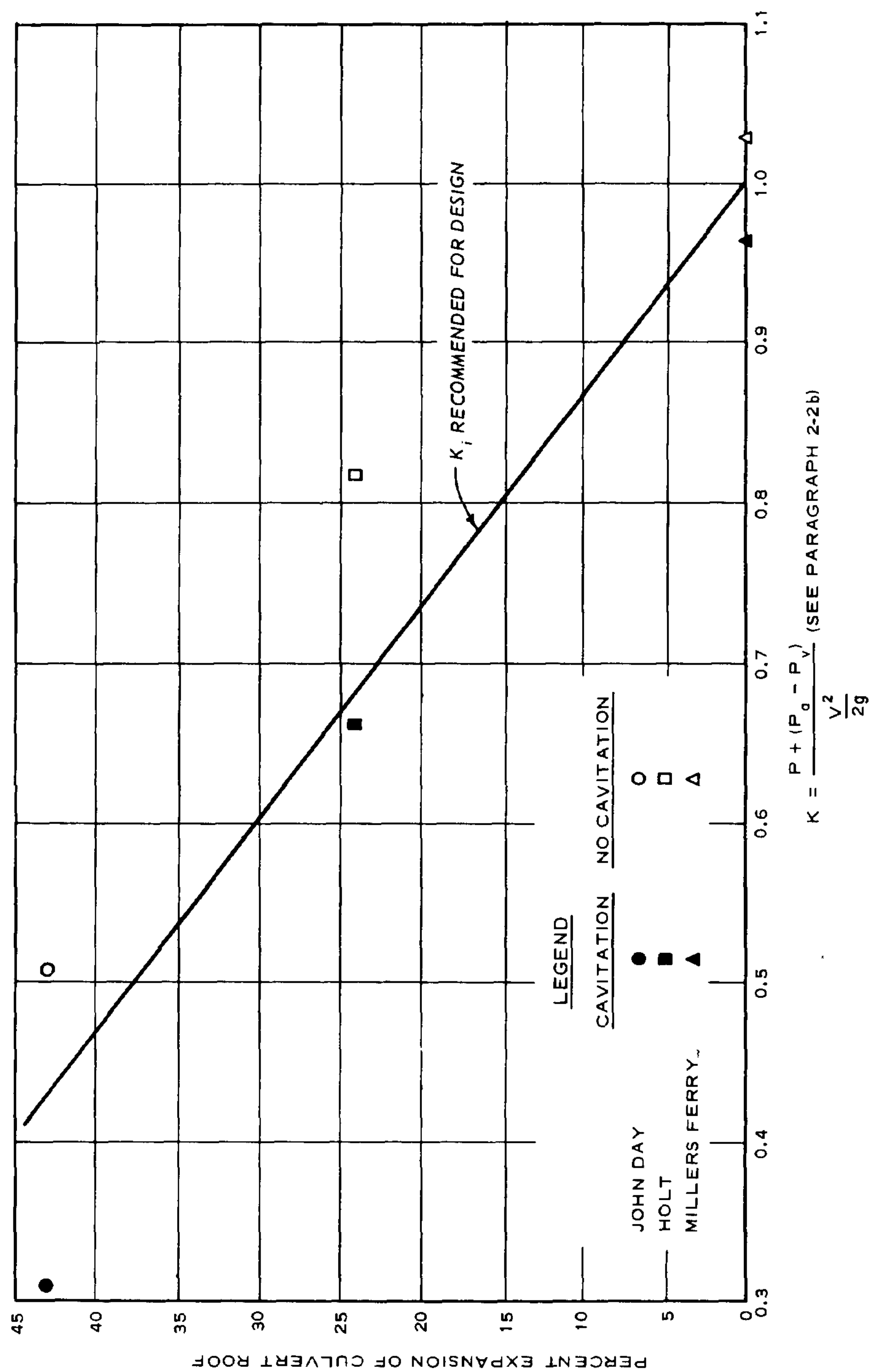

Figure 2-1. Cavitation index

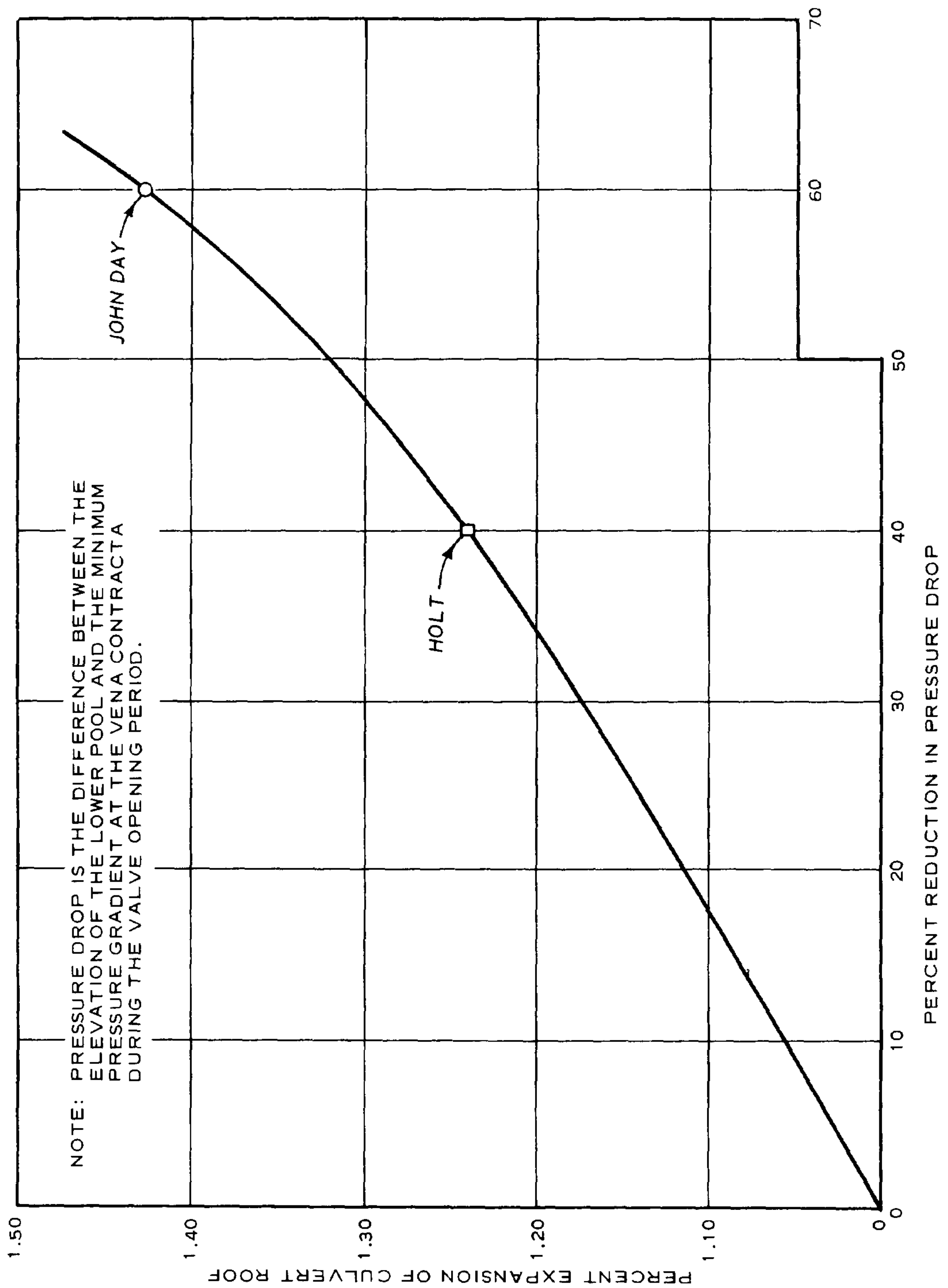

Figure 2-2. Effect of roof expansion on pressure gradient

and not recommended is water-venting by lateral inflow from the lock chamber into the low pressure zone.[d,e] Such water vents will raise the pressure in the critical zone, an asset; but also the lateral inflow will increase turbulence in this zone, a liability. Systematic field tests would be required to determine whether lateral water vents actually are beneficial or detrimental and to establish design rules for their use.

c. In addition to the requirements listed in paragraph 2-3a, in all cases, the highest point in the culvert system between the filling and emptying valves should be at least 5 ft below the lower pool to assure that air will not seep into the culverts when the lock chamber water surface is at the level of the lower pool.

d. Design examples are given in Appendix C.

2-4. Conclusions and Recommendations Regarding Admission of Air into Culvert System. It is concluded that air pockets in the culvert filling system are hazardous but that air bubbles well entrained in the flow can be beneficial. Thus it is proposed that:

a. All elements of the culvert system between the filling and emptying valves should be at least 5 ft below minimum lower pool.

b. In locks with lifts of 40 ft and less, air should be sealed from the culvert system during filling operations. In low-lift locks, where turbulence levels are low, even small amounts of air admitted during filling could collect in pockets and become dangerous. The lock valves should be placed at an elevation that will result in the minimum value of K being greater than K_i and as a safety factor, the valves should be at an elevation equal to at least one-tenth of the lift less than the elevation required for minimum K to equal K_i. It is indicated in Example 1, Appendix C, that this will not require excessive submergence of the culverts and therefore, in most cases, should not prove costly.

c. In locks with lifts of 60 ft and greater, the valves should be placed at an elevation that will result in about 10 ft of negative pressure on the culvert roof during filling and air vents should be provided in the low pressure zone. An exception could be made in the very unlikely case that foundation conditions are such that it is economically desirable to place the valves very deep with respect to lower pool. Consideration of Example 2, Appendix C, provides insight into the submergence that would be necessary to prevent cavitation.

d. In locks with lifts of 40 to 60 ft, decision as to whether cavitation will be prevented by submergence or admission of air should be based on economic considerations for the particular project.

2-5. Design of Air Vents.

a. All filling-valve air vents should be provided with means for controlling the amount of air entering the culvert system. Bulkhead slots, valve wells, or other such openings into the culvert should never be allowed to double as air vents for the filling valves.

b. Air vents for emptying valves should be controlled, the same as for filling valves, if flow is discharged into the lower approach to the lock. However, if flow is discharged outside of the lock approach, excessive air is not likely to be harmful and bulkhead slots can be used to double as air vents.

c. A satisfactory vent system for a valve would consist of two independent 12-in.-diam pipes entering flush with the culvert roof between the quarter and third points across the culvert. A vent slot extending across the roof of the culvert as provided in flood control conduits is not required. The vents should enter the culvert roof within the low pressure zone which extends from the valve to the vena contracta of the jet passing under the valve. Location of the vena contracta varies with culvert height and valve opening but vents have performed satisfactorily when placed no more than a distance of one-half of the valve height downstream from the valve well. The vent pipes should be brought through an accessible location, such as the platform that supports the valve operating machinery, and then to openings on the outside face of the lock wall at an elevation above the maximum pool at which the lock will be operated. Openings on the top or inside face of the lock wall are nuisances to personnel on the wall or in the lock chamber. A valve should be inserted in each vent at the accessible location. At the time the lock is put in operation, hydraulic design personnel should assist in determining vent valve settings that will preclude cavitation without an excessive amount of air and thus added turbulence in the lock chamber or lower approach. This should not be difficult as past experience has shown that satisfactory performance can be obtained within a range of settings. The vent valves should be locked in the desired position to prevent accidental changing of the setting.